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None

(58) Field of search
UK CL (Edition F) H4L, H4P

(54) Communications systems

(57) A communications system of high resistance to interference and jamming is of a frequency hopping type. In each hop period portions of data are simultaneously transmitted on 16 respective pseudo-randomly selected frequency channels. Preferably the data is first encoded using concatenated Reed-Solomon and Reed-Muller encoders (42, 46) the data to be transmitted is also symbol interleaved and then expanded by Direct Sequence Spread Spectrum. Resulting subsets of data from the said portions are thus encoded in both time and frequency domains.

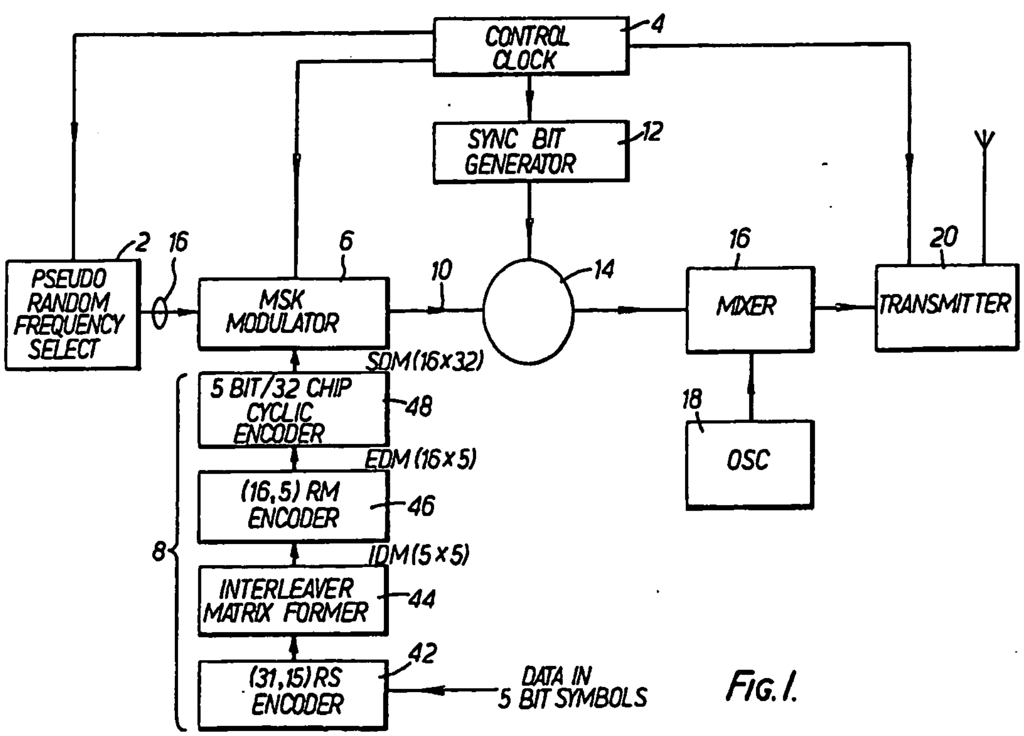

FIG. 1.

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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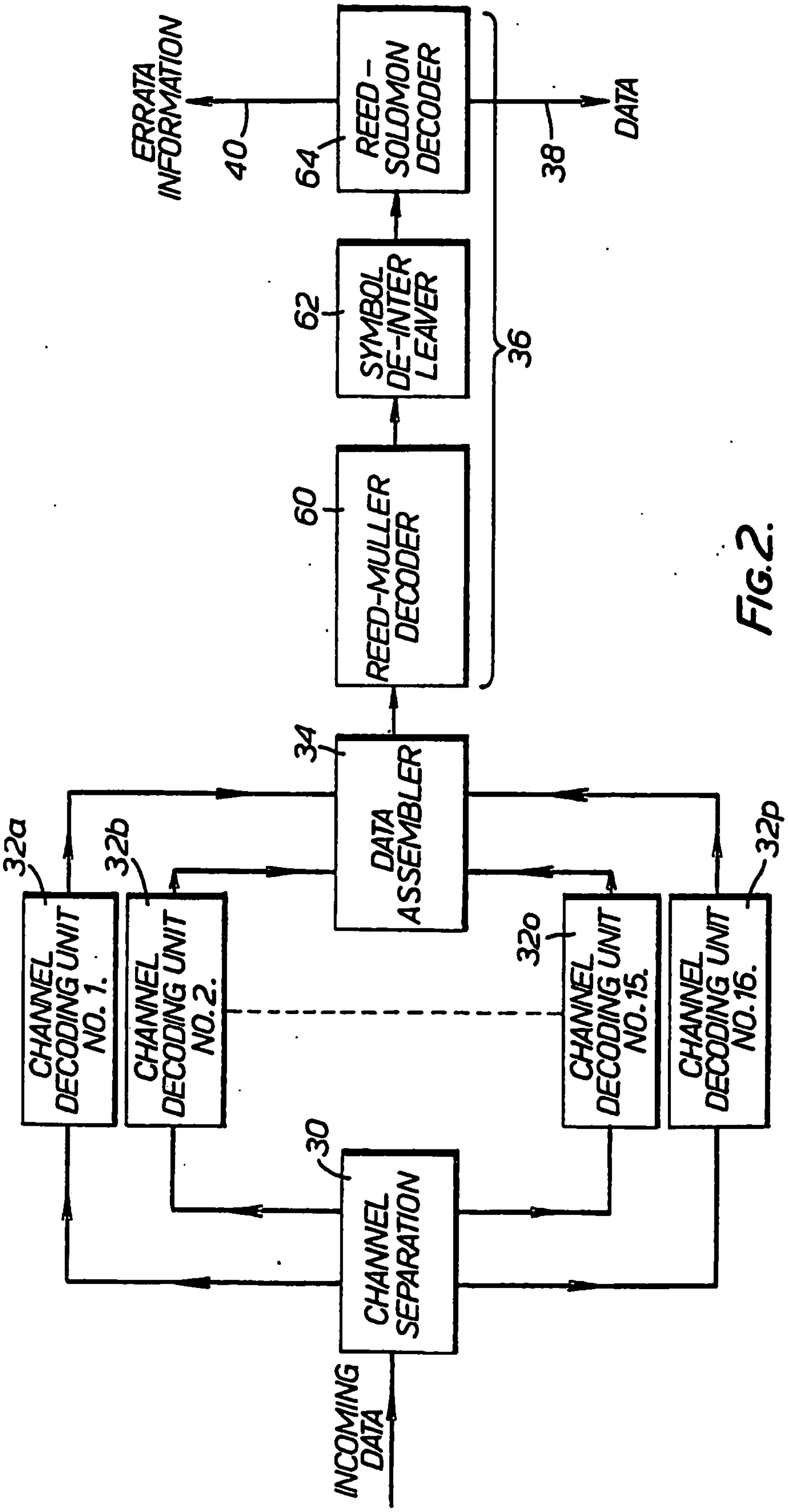

ERRATA INFORMATION
40
64
REED-SOLOMON DECODER
38
DATA
62
SYMBOL DE-INTER LEAVER
36
60
REED-MULLER DECODER
34
DATA ASSEMBLER
32a
32b
32o
32p
CHANNEL DECODING UNIT NO. 1.
CHANNEL DECODING UNIT NO.2.
CHANNEL DECODING UNIT NO.15.
CHANNEL DECODING UNIT NO.16.
30
CHANNEL SEPARATION
INCOMING DATA

FIG.2.

COMMUNICATIONS SYSTEMS

The present invention relates to communications systems and, more particularly to such systems which are resistant to various types of jamming systems, both existing types of jammers and those which may not yet have been produced but which may be developed to fulfill certain defined requirements in the future.

Frequency hopping radios are resistant to various jammers as they hop their carrier frequency periodically during the course of a transmission over a predetermined number of channels in accordance with a pseudo-random sequence. Some of the channels used during a transmission may be effectively "blocked " by jammers or for other reasons. However it is usually possible with the use of suitable coding techniques to transmit information with reasonable accuracy against the effects of static jammers or noise/chirp jammers provided only a relatively small proportion of the channels are blocked.

However it may be possible to design a "follow jammer" which would be capable of following the pseudo-random sequence of channels being used by a frequency hopping

of these and similar suitable codes may be found in the following references:

a) Macwilliams F.J. and Sloane N.J.A. "The Theory of Error Correcting Codes" published by North-Holland 1977, ISBN 0444 84009 0 1977;

b) Reed I.S. amd Solomon G. "Polynomial Codes over Certain Finite Fields" J. Soc.Ind. Appl. Math. Vol.8 pp.300-304 June 1960;

c) G.D.Forney Jr. "Concatenated Codes" M.I.T.Research Monograph No.37 1966;

d) Chien R.T. "Burst-Correcting Codes With High-Speed Decoding" Bell System Technical Journal, Vol.27, pp.379-423, 623-656; and

e) Berlekamp E.R., "The Technology of Error-Correcting Codes", Proc.lEEE, Vol.68, No.5 May 1980 pp.564-593.

The likelihood of an error being introduced in a transmitted digital bit in a data transmission is known as the bit error rate (BER). For a channel blocked by a noise jammer the BER will be 0.5. With such an error rate no certainity can be attached to the value of any

declared "erasures". If a bit or symbol is received, believed to be correct but is actually not correct then it is referred to as "erroneous". If a bit or symbol is received, believed to be correct and is actually correct then it is a "correct" bit or symbol.

Reed-Solomon (RS) codes are symbol codes which can work on combinations of erased and erroneous symbols. Such codes are capable of correcting erasures more efficiently than errors as each error has first to be located and then corrected. The (31,15) RS code has 16 redundant symbols in each 31 symbol code word. Suppose a code word has S symbol errors and T erasures then the decoder can correct the code word completely if and only if 2*S + T is less than or equal to 16.

The technical problem posed in the present application is to provide an efficient communications system which may be used in conjunction with known coding techniques to provide high resistance to a variety of jamming techniques.

This problem is solved in accordance with the invention by providing a communications system comprising a transmitter adapted to transmit simultaneously information modulated onto a plurality of different

Figure 2 is a block diagram of a receiver for a communications system including the transmitter of Figure 1; and

Figure 3 is a detail of a channel decoding unit for use in the receiver of Figure 2.

The communications system to be described primarily comprises a pseudo-random frequency selection device 2 which is controlled by an output from a control clock 4. The frequency selection device 2 periodically outputs a pseudo-randomly selected set of sixteen frequency channels which are fed to an MSK modulator 6. The sixteen selected frequency channels are used during a succeeding hop period. These frequency channels are selected from a predetermined set of channels, for example 256 channels spaced from one another by, for example, 25 kHz.

The MSK modulator 6 is also supplied with data which has preferably been encoded in encoding apparatus 8 to be described in more detail hereinafter. A selected subset of the data bits to be transmitted during each hop period are modulated onto each of the sixteen selected frequency channels to be used during that hop period and simultaneously output along a line 10.

divides the incoming signals into the sixteen frequency channels used for transmission. Each frequency channel having its own data modulated thereon is fed to an individual channel decoding unit 32a, 32b...32o and 32p. The channel decoding unit 32 is shown in more detail in Figure 3 and will be described later. The data recovered from each channel is then assembled in a data assembler 34 and preferably fed through decoding apparatus 36 which recovers the original data as encoded by the encoding apparatus 8 in the transmitter. This data is output along line 38. The decoding apparatus 36 may also produce on line 34 a variety of information indicative of the number and positions of errors located in the received data.

It will be appreciated that an important aspect of the communications system so far described is the transmission of data simultaneously on a number of channels which are pseudo-randomly selected; i.e. bear no obvious relationship with one another that is carried forward from hop period to hop period. Thus, whereas with a frequency hopping radio system, a follow jammer could effectively prevent communications taking place, the described communications system when operating in the presence of a single follow jammer would only have one of its sixteen channels impaired

are separated into five groups of 15 symbols each. Each group of 15 symbols is encoded in a Reed-Solomon encoder 42 using a (31,15) RS code. Each group of 15 symbols then becomes a code word of 31 symbols. At the output of the encoder 42 after all 375 bits of the message have been encoded with the (31,15) RS code there will be five coded words each of 31 symbols. These five coded words of 31 symbols are then symbol interleaved to depth 5 so that the first symbol from each of the five code words of 31 symbols are adjacent each other in sequence after the interleaving has been carried out, and are followed by the second symbols from each code word and so on until all 155 symbols have been interleaved. The interleaving process is carried out in an interleaver matrix former 44 which outputs a series of 31 initial data matrices (IDMs). Each IDM consists of one symbol from each of the 31 RS encoded code words in each row. Each symbol consists of 5 data bits so each IDM is a 5 x 5 matrix. The data to be transmitted during each hop period will be derived from the data contained within a single initial data matrix. Therefore as the 375 bit message consists of 31 IDMs it will be necessary to transmit the message over 31 hop periods. Each IDM is passed to a (16,5) RM encoder 46. The encoder 46 applies a (16,5) Reed-Muller code to each of the five columns of the IDM.

successive hop periods in order to complete transmission of the 31 IDMs representing the whole of the 375 bit message to be transmitted. If there are further message sections then these are encoded in a similar manner and separately transmitted.

At the receiver 16 the channels transmitted during each hop period are separated by channel separation device 30. Each separate channel is then fed to an individual channel decoding unit 32. In this decoding unit, which is illustrated in more detail in Figure 3, each 5 bit row of the EDM as fed to encoder 48 is restored.

In the decoding unit 32 the data is first fed to a hard limiter 50 which shapes the incoming waveform so that it represents a 32 chip sequence. Thus the limiter 50 reduces to some extent the effects of random noise introduced during transmission. The output of the hard limiter is then fed to an analogue correlator 52 in which the received 32 chip sequence is correlated with the fixed chip sequence used in the encoder 40. This fixed chip sequence is fed to the correlator 52 from a reference signal source 54. As the fixed chip sequence has a good auto-correlation property, the output of the analogue correlator 52 peaks at the time when the reference signal is subject to the same number of

IDMs received over 31 consecutive hop periods are accumulated in the symbol de-interleaver 62 and after receipt of the 31st IDM each 31 symbol code word can be de-interleaved and fed to the Reed-Solomon decoder 64. The Reed-Solomon decoder decodes each code word of 31 symbols applying the inverse of the (31,15) RS code used in encoder 42. The decoder 64 output the 375 bit message originally transmitted on line 38 together with errata information on line 40.

The encoder and decoder used in the transmitter and receiver described may be of various types commercially available. They may also be implemented using the known encoding and decoding algorithms using suitable microprocessors, or mini computers.

It will be appreciated that the described coding scheme not only takes advantage of the concatenation of Reed-Solomon and Reed-Muller codes, but also has the associated advantages provided by the spread spectrum techniques introduced by the 5 bit/32 chip encoder and the use of 16 pseudo randomly selected channels during each hop period. Thus the data is effectively encoded in the time domain by the interleaved Reed-Solomon code and in the frequency domain by the frequency selection device 2, the Reed-Muller code and

CLAIMS

1. A communications system comprising a transmitter adapted to transmit simultaneously selected subsets of information, each subset being modulated onto a respective one of a plurality of different frequency channels pseudo-randomly selected from a predetermined set of frequency channels for a predetermined hop period, the plurality of frequency channels being reselected for each hop period.

2. A system as claimed in claim 1, further comprising means for encoding data to be transmitted to provide said information.

3. A system as claimed in claim 2, wherein said encoding means comprises means for employing concatenated codes.

4. A system as claimed in claim 2 or 3, wherein the code or codes employed are selected from Reed-Solomon codes, Reed-Muller codes and Hamming codes.

5. A system as claimed in any one of the preceding claims, further comprising spectrum spreading means operative on data to be transmitted to provide said

code.

11. A method as claimed in claim 10, wherein the first code is a Reed-Solomon code and the further code is a Reed-Muller code.

12. A method as claimed in claim 10 or 11, wherein the encoding step further comprises interleaving the data encoded by the first code before encoding with the further code.

13. A method as claimed in any one of claims 9 to 12, further comprising spreading the spectrum of the encoded data prior to transmission.

14. A method of transmitting data substantially as herein described with reference to the accompanying drawings.

8323:17BEC1

Category	Identity of document and relevant passages	Rele t to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

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